7TH WCTR
SYDNEY AUSTRALIA
1995

TOPIC 14
PERFORMANCE
MEASUREMENT

A SENSITIVITY ANALYSIS OF TOTAL FACTOR PRODUCTIVITY MEASUREMENT: EVIDENCE FROM RAIL PRODUCTIVITY STUDIES

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Abstract

Using data on total factor productivity (TFP) for Canadian railways, the sensitivity to various assumptions and computational procedures are examined including: choice of index formula; choice of time period; alternate depreciation assumptions; alternate weights on capital; aggregation of outputs and inputs. TFP results are more sensitive than is widely recognised.

INTRODUCTION

There is a wide consensus among economists that total factor productivity (TFP) is the best overall measure of the performance of firms or industries (Hensher 1992). The measure does not suffer from the limitations of other partial productivity measures, such as the widely cited labour productivity (eg output per person). High labour productivity may be high due to investment in capital or technology. A comprehensive performance measure needs to consider all inputs, not just labour. Over the years, an increasing number of studies have measured TFP for various industries and firms. Perhaps because of the availability of consistent government published or collected data, transportation industries especially have been the subject of TFP measures. Indeed, TFP measures have often been important pieces of evidence leading to policy reform (eg Caves, Christensen and Swanson 1981a, 1981b), and for measuring the effectiveness of policies (eg Gillen, Oum and Tretheway 1987). In the US rail industry, TFP is now measured on a regular basis, and used in the setting of price caps on regulated rates. This was the outcome of the US Interstate Commerce Commission *Ex Parte 290* proceedings; see Waters and Tretheway 1991 for a summary.

In an earlier paper (Oum, Tretheway and Waters 1992), the authors reported on the various uses of TFP and other measures of productivity. Building on Diewert (1989 and 1991), that paper distinguished between gross TFP measures encompassing productivity gains from all sources (appropriate for use in setting price caps, for example), and narrower measures of technical change (appropriate for assessing gains from policy reform, for example). Technical change is a narrow concept of productivity measured by the shift in cost/production functions, typically estimated by econometric methods. The index number approaches and econometric cost function approaches can be linked directly depending on assumptions about returns to scale, density and other endogenous influences on productivity (see Denny, Fuss and Waverman 1981; Fuss 1994), or by "decomposing" index number estimates of TFP by regression analysis (Freeman et al. 1987, Chapter 6, Appendix 2; Tretheway 1987). A rigorous discussion of alternate concepts of TFP is Diewert (1989, 1991).

However, no studies which we are aware of systematically examine the sensitivity of TFP measures to alternative assumptions and techniques about the data and computation procedures. As a practical matter, researchers know that use of different rates of economic depreciation, different levels of disaggregation of outputs, different index number formulations, etc., can lead to different results. Yet TFP studies state their assumptions and proceed to measure TFP. It is rare that the researcher reports what the effect of alternative assumptions would have been. This paper attempts to rectify this by taking a single data set for the Canadian rail industry and reporting the effects of alternative assumptions. As will be seen, TFP results can vary quite significantly.

Our general conclusion is that TFP measures are in fact sensitive to assumptions made. Empirical evidence on sensitivity of TFP measures to the assumptions required to undertake measurement will be valuable to researchers and to policy analysts who must make use of empirical findings. We think that in the future, researchers should report sensitivity results in their TFP studies.

The rail industry is a good choice for this effort, since it is perhaps the industry with the greatest number of studies of TFP. The TFP performance of this industry has been examined in North America, Australia and Europe. We utilize a data set for the two Canadian railways, CN and CP for the period 1956-1991. This period covers the era from the end of steam power to substantial deregulation of the industry in the 1980s. There is great similarity in the operating conditions of the two railways, at least relative to that in other countries. The two carriers are both transcontinental carriers, operating in identical climatic and terrain conditions, serving generally similar markets. Their route systems are generally parallel to each other at a macro level. Both have extensive operations in the US although these are not included in the data base. One of the carriers is privately owned (CP) while the other is a government business enterprise (or crown corporation). For this paper, we limit the sensitivity analysis to the period 1981-1991, a period of great importance to the Canadian rail industry as it responded to deregulation of competing US railroads, and eventually to Canadian deregulation as well. (Chapter 6 of Appendix A of Tretheway, Waters and Fok 1994, provides a sensitivity analysis for the full period). It is also a period for which a disaggregate output index was available.

Our sensitivity analysis covers the effect on TFP calculations of:

1. the choice of index number formula;
2. the choice of calculation period;
3. alternate depreciation assumptions;
4. alternate costs of capital and weights for capital inputs;
5. composition/aggregation of outputs; and
6. aggregation of inputs.

THE DATA BASE AND MEASUREMENT OF CAPITAL INPUTS

The data base employed in this study is documented in some detail in Tretheway, Waters and Fok 1994 (henceforth TWF). Output for the 1956-91 period was measured as an index number of aggregate revenue tonne-kilometres (because more disaggregate freight traffic statistics were not available for the whole period), intercity passenger-kilometres and commuter passenger-kilometres. Much of the passenger service in this period was provided by VIA rail, which contracts with CN and CP for rail services. It was necessary to impute VIA rail outputs to CN and CP to be consistent with early years' data (VIA Rail's own inputs and costs are not included; only revenues received and costs incurred by CN and CP are in the data base). For the 1981-91 period, an output index with a higher degree of disaggregation was available.

Input categories included: (1) fuel and energy; (2) labour hours (an index of four labour categories); (3) way and structures (W&S) capital; (4) equipment capital (rolling stock); (5) land; and (6) "materials" or "other purchased inputs" (defined as residual expenses deflated by a price index). Input indices were constructed for each category, and a weighted aggregate input index was used for productivity measures.

All aggregation was done using a Tornqvist discrete time approximation of the divisia index. Outputs were aggregated with revenue shares as weights, and cost shares were used for input weights. The output weights form an "all sources" measure of TFP. Using an estimate of marginal costs (cost elasticity weights for outputs) forms a narrower, technical change concept of productivity (see Caves, Christensen and Swanson 1981b, Denny, Fuss and Waverman 1981; also the discussion in Oum, Tretheway and Waters 1992).

Capital was treated using the method of Christensen and Jorgenson (1969), although we developed a service price formula which allowed capital to be financed by both debt and equity. The Christensen and Jorgenson approach assumes all capital is financed by equity, although paradoxically most studies, included rail industry productivity studies conducted by Caves, Christensen et al. use a debt rate as the price of equity. Capital stocks were estimated by a perpetual inventory method using economic rates of depreciation. Our capital investment series extended back as far as 1890 in the case of CP and into the 1920s for CN. Capital usage (service) price is a function of the cost of financial capital, economic depreciation, capital gains on assets, and various taxation factors. A lower service price was used for CN reflecting the lower cost of capital for the government-owned firm.

SENSITIVITY TO THE INDEX NUMBER FORMULA

We employ the Tornqvist index formula (also known as a divisia or translog index) rather than the simpler Laspeyres or Paasche index formulae. The different index formulae can result in a difference in growth rates; however, because the Tornqvist index is preferred over the simpler indices for several reasons (see Diewert 1991), we have not made any calculations with Laspeyres or Paasche indices (Tornqvist indices lie in between the values from Laspeyres and Paasche indices).

However, we do compare our calculated TFP growth using a multilateral index (an index which allows absolute comparisons of productivity levels in the two firms and not just their growth rates of productivity) to results using a chain-linked time series (CLTS) index for each firm by itself. Both of these are Tornqvist forms, and the multilateral form is coming into increasing use in order to make comparisons of absolute levels of productivity between firms. The chain-linked index compares year to year changes in TFP growth for one company. The multilateral index compares each year's observation for one railway to the mean of both railways' data series.

Table 1 shows the results of our alternative measures of TFP. The first row shows our base case results, using the assumptions in our 1994 study. The second row gives the first sensitivity comparison. Here, the CLTS method results in a higher TFP growth of CN for 1981-91 (3.5 versus 3.0 percent), and a lower TFP growth rate for CP (2.5 versus 2.7 percent with the multilateral index). That is, a productivity growth calculation for a firm in isolation is different from the broader pooling of data necessary to make direct comparisons between the firms. The reason for the difference is that the CLTS results in a lower weight to capital inputs for CN because the mean reference point in the combined data set would include CP's higher capital service price. Conversely, CP's measured TFP growth slips with the individual CLTS calculation because CP's higher capital service price results in a higher weight on capital inputs which have not been shrinking as fast as other inputs.

Table 1 Summary of sensitivity tests average annual TFP growth 1981-1991

	CN	CP	combined†
Base results	3.0	2.7	2.9
Alternate index number method: CLTS	3.5	2.5	2.9
Alternate time period			
1980-1991	3.0	2.3	2.7
1981-1990	2.4	2.0	2.3†
1982-1991	3.9	2.7	3.3
Alternate depreciation method			
constant .04 & .08	3.3	3.0	n.a.
constant .06 & .12 (50% increase)	3.6	3.2	n.a.
CP suggestion: .08 & .14	3.9	3.2	n.a.
Alternate cost of capital or capital weight			
VFP (zero weight on capital)	4.5	4.2	n.a.
CP service price used for CN	2.8	2.6	n.a.
actual avg. return on equity (CN 0.0 to 1981, 1.1% thereafter; CP 2.8 to 1981, 8.3 thereafter)	3.3	3.0	n.a.
TFP from Economy-wide Perspective			
CP's service price for CN plus govt. grain cars	2.8	2.5	n.a.
Output composition, disaggregation			
agg. output less passgr. (frt. tonne-km. only)	3.4	2.9	3.0
Transport Canada detailed industry output	n.a.	n.a.	1.4†
CP internal detailed output index	n.a.	1.8	n.a.
Input and Output disaggregation			
CP detailed labour input index (0.5% slower decline) and CP internal detailed output index	n.a.	1.6	n.a.

Notes:

† industry aggregate (CN and CP combined) is for 1981-1990 to match availability of Transport Canada output index. Also note that CP's service price is used to weight CN's capital inputs in constructing the industry aggregate, ie it is not a simple average; therefore industry TFP growth can be closer to one railway or the other depending on underlying data characteristics.

SENSITIVITY TO THE CHOICE OF TIME INTERVALS

This can be an important influence on calculated average growth rates. While the average growth rate over a period is not influenced by fluctuations *between* the starting and ending point, the calculated growth rate *is influenced by the starting or ending date*. For example, Table 1 shows CN's growth rate from 1982-1991 is 3.9 percent compared to the base case result (1981-1991) of 3.0 percent. CN traffic felt the 1982 recession more than CP. Measuring productivity growth from a recession year can be misleading; it would overstate productivity growth because the output recovery following the recession would be mistakenly recorded as a productivity gain. Changing the terminating date from 1991 to 1990 reduces measured TFP growth for both carriers by about 0.6 percentage points, again, a substantial change.

SENSITIVITY TO ALTERNATE DEPRECIATION ASSUMPTIONS

There is no agreement on the appropriate rate of economic depreciation of rail assets, especially aggregated collections of assets. Assumptions must be made. We use proportional depreciation: the usefulness of assets are assumed to decline at a constant proportional rate. This is a convenient assumption (it means that assets acquired in different years can be added together providing they are measured in constant dollars) and there is some empirical evidence to support use of proportional depreciation (Hulten and Wykoff 1981).

Our base depreciation assumption includes an escalating depreciation rate after 1975. Real economic depreciation for road and structures is assumed to have increased gradually from .04 p.a. to .055 by 1991; similarly, the base figures have equipment depreciation rising gradually from .08 to .10. This reflects a hypothesized increased rate of capital use and/or obsolescence in recent years. The effect of these assumptions is to lower measured TFP growth over the 1980s by 0.3 percentage points. That is, using constant depreciation rates of .04 and .08 for way and structures and equipment capital, respectively, would raise the base results from 3.0 to 3.3 percent for CN, and from 2.7 to 3.0 percent for CP.

Increasing depreciation rates across the board has partially offsetting effects. Higher depreciation increases the service price (hence the weight assigned to capital inputs relative to other inputs), but higher depreciation means capital stocks accumulate more slowly hence there is a decline in the relative growth rate of capital inputs. For illustration, we arbitrarily increase constant depreciation rates by 50 percent, ie from .04 to .06 for way and structure capital, and from .08 to .12 for equipment capital. Table 1 shows that the net effect is to increase TFP growth slightly, by about one-half percentage points for each railway. We make one other modification of depreciation rates. CP suggested a variation on our depreciation formula based on assumed salvage values and economic lives of assets. This involves even higher depreciation rates (.08 and .14). This further increases measured TFP growth for CN but not CP (the change was positive but rounding off resulted in no change for CP).

SENSITIVITY TO ALTERNATE CAPITAL WEIGHTS

Capital inputs and the weight (price) attached to capital inputs is perhaps the most controversial part of input measurement in TFP analysis. One test of the influence of capital inputs on TFP measurement is to eliminate capital inputs entirely from the productivity calculation. This is indicated by the concept of variable factor productivity (VFP) in Table 1 (Tretheway 1987). Capital inputs have tended to grow rather than decline on average over the 1980s, unlike most other input categories. Therefore, eliminating capital inputs from the productivity calculation will result in higher productivity figures. Measured TFP growth over the 1980s increases by 1.5 percentage points for both railways if capital inputs are ignored.

Our base results recognize that the government-owned CN has a lower service price of capital because of lower interest and equity costs, and freedom from income taxation in nearly all years.

How does this affect the productivity calculation? In Table 1, using CP's capital service prices for CN lowers CN's average TFP growth from 3.0 to 2.8 percent. It also lowers CP's TFP growth from 2.7 to 2.6 percent; changing the CN weights on capital also changes the combined mean, which in this case, also causes a change in the calculated growth rate for CP even though none of its figures were changed. This is a property of multilateral indices. Consistent with its lower service price, CN use of capital has tended to grow faster than that of CP (Waters, Tretheway and Fok 1995).

The regular capital service price uses the concept of a market required rate of return on equity (and/or a regulatory-approved rate). Required market rates of return are consistently higher than actual rates of return earned by the railways. For illustrative purposes, we replace these market-required returns on equity (ROE) with the average actual return on equity (ROE) over two periods. We assign a zero value for CN prior to 1981 (ROE for nearly all years were negative), and a rate of 1.1 percent thereafter. Corresponding figures for CP are 2.8 and 8.3 percent. Compared to the base case, CN's measured TFP growth rises by 0.3 percentage points to 3.3, while CP's rises from 2.7 to 3.0 percent.

TFP GROWTH FROM A MANAGERIAL PERSPECTIVE VERSUS THE ECONOMY LEVEL

We have interpreted our TFP calculations as measures of *managerial* performance. Recognizing that the managers of government owned CN face a lower cost of capital we have employed the lower capital service price for CN compared to CP. But capital has the same opportunity cost to *society* whether capital is employed by a publicly-owned or privately-owned company. To assess performance in the rail industry from an economy-level perspective, we apply CP's service price to CN as well as CP (other input costs are no different). Applying CP's service price of capital to CN was reported above (average TFP growth of 2.8 and 2.6 percent for CN and CP, respectively; this is row 10 in Table 1). Using CP's service price reduces both CN's and CP's TFP growth by 0.2 points compared to the base results. CP's TFP measure is reduced because, when using a multilateral index, changing values for one firm will result in changes to the value of the mean, and hence to computations of productivity for other firms.

SENSITIVITY TO ALTERNATE OUTPUT COMPOSITION OR DISAGGREGATION

Our base results include two types of passenger outputs and aggregate tonne-kilometres of freight. Deleting passenger outputs would increase the measure of TFP growth for both carriers. The freight tonne-kilometre output measure shows CN productivity growth at 3.4 percent and that for CP of 2.9 percent, ie average TFP growth increased by 0.4 and 0.2 percentage points, respectively.

We have noted that using freight tonne-kilometres for freight implicitly assumes that all freight is the same. But some types of traffic require less inputs than others. *Shifts in traffic mix toward less input-using outputs will give rise to apparent productivity gains as measured by tonne-kilometres, but this is due to a change in traffic mix rather than real productivity gains.* A shift to lower input-using outputs could reflect deliberate strategy by management, but it may also reflect exogenous shifts in traffic demand. In either case, this is quite different from changes in the ability to supply outputs from inputs which is what productivity tries to measure.

We can carry out two tests of the sensitivity of our TFP growth rates to the aggregation over all traffic types. It is possible to develop a disaggregate output index for the Canadian Class I rail industry (two railways, Canadian National and CP Rail) for the period 1981-1990. Transport Canada developed an output *price* index based on the National Transportation Agency's (NTA) waybill sample for CN and CP combined (Transport Canada 1992). 320 commodity categories were aggregated into 14 commodity classifications; the possible origins and destinations were grouped into five Canadian regions. There is a potential of 25 origin-destination pairs including intra-regional traffic, times 14 commodity classifications, is a total of 350 possible output categories. Price indices were prepared for the 14 commodity classifications, and aggregated to an overall price index. The Transport Canada output price index is a freight only output index. We combined our passenger outputs (for CN and CP combined) with the Transport Canada freight index. This new index is available for 1981-1990. Dividing total revenues by an output *price* index results in an output *quantity* index. Because the output price index is developed for a number of output classifications, the resulting output quantity index is adjusted, at least partially, for shifts in traffic mix.

The base industry TFP growth for these years is 2.3 percent (line 4 in Table 1). Using the disaggregate output index to remove the effect of shifts in traffic mix reduces measured TFP growth to 1.4 percent—that is, almost a full percent of the measured TFP growth using freight tonne-kilometres is the result of shifts in traffic mix rather than actual productivity gains.

A second disaggregate rail output index in Canada is an internal output index developed by CP Rail. They computed revenue tonne-miles for 69 commodity categories, weighted by actual revenues (ie confidential contract revenues are used where applicable). The CP Rail index is for freight only; we added rail passenger outputs to their index in order to compare it with our simpler output index consisting of total freight tonne- and passenger-kilometres. Once again, the output growth with a disaggregate index is substantially less than with the aggregate index. Adopting this output index lowers CP's TFP growth from the base case result of 2.7 percent to 1.8 percent. Again, almost a full percentage point of TFP growth apparently is related to shifts in traffic mix. To put this finding in perspective, almost one third of the measured productivity disappears when a more disaggregate measure of output is used, underscoring the sensitivity of TFP results. We find a similar impact of output disaggregation in measuring TFP for the US Class I railroad industry, see TWF (1994: 45-49).

SENSITIVITY TO INPUT DISAGGREGATION

Ordinarily researchers are unable to investigate how further disaggregation of inputs would affect TFP calculations—they must use what data are available. We were able to carry out one test. CP developed a more detailed labour input index than we could construct from the annual report. Our labour index had four labour categories; theirs had 64. CP provided us with their data base. To their 64 categories, we added passenger-related labour (since we include passenger service in our output measure).

Table 2 Average annual rates of growth CP rail labour indexes 1981-1991

68 categories of labour	4 categories of labour	Total Service Hours
-3.9%	-4.4%	-4.6%

During this period, the quantity of railway labour was declining. In fact the decline in labour use seems to be a long term trend dating back to the 1930s. For the period 1981-91, the more detailed labour index showed labour inputs falling 0.5 percent less quickly than the simpler index. Essentially, as CP shed labour, it retained more of the high value labour types, and shed relatively more in the less skilled categories. Table 2 compares the growth rates (negative) of labour inputs over the 10 year period 1981-91. In this instance, the change from four labour categories to 68 resulted in a 0.5 percent difference in labour input growth, ie using four labour categories, the rate of decline of labour inputs is -4.4 percent whereas using 68 labour categories shows an average decline of -3.9 percent per annum. Data for an even simpler measure of labour input, total service hours, is also provided for comparison.

In terms of this effect on TFP growth calculations, using our aggregate output index, CP's more detailed labour index reduces the base result from 2.5 percent (this is the chained-link time series result, line 2 in Table 1) to 1.8 percent. By combining use of CP's disaggregate output index and more detailed labour index, measured TFP growth is further reduced from 1.8 percent to 1.6 percent.

SUMMARY OF SENSITIVITY TESTS AND CONCLUSION

Despite the extensive and careful development of the primary data base, the calculation of TFP growth rates is shown to be sensitive to a variety of underlying assumptions and calculation procedures. Using CP Rail as an example, measured per annum growth in TFP varied from the base calculation of 2.7 percent to as high as 4.2 percent and as low as 1.6 percent. Even excluding the 4.2 percent case (which gave no weight to capital), the range is 3.2 percent to 1.6 percent, a two-to-one ratio.

Comparisons of TFP growth rates across different studies are not likely to be reliable. Even for a given data base such as ours, different calculations can produce up to a percentage point and more difference in calculated TFP growth rates. It is essential that one understand the underlying data base and calculation assumptions to evaluate reported TFP growth rates.

That said, the sensitivity tests do not show that all these calculations are unreliable. There is a noticeable consistency in the results. Excluding the disaggregate output indices and the VFP calculation (which ignores capital inputs), the magnitude of TFP growth rates hover in a range of about 2.4 to 3.9 percent for CN, and from 2.0 to 3.2 percent for CP. The relative ranking of the two companies in TFP growth is quite consistent. The long term performance trends show the two railways to be very close in TFP growth. The figures also show consistently that CN's *recent* TFP performance exceeds that of CP, although this particular result is influenced by some differences in labour classifications. We note in TWF that the apparent higher productivity by CN during 1981-91 is largely explained by a labour reclassification in 1981-82 which overstates reductions in labour inputs hence overstates productivity growth. This does not undermine our conclusions here, as all comparisons used the same labour data for CN.

We conclude that measures of TFP growth rates are much less precise than is popularly believed. Researchers measuring TFP should carry out and report on a sensitivity analysis so readers can better appreciate the reliability of the estimates and the factors which are most important for the particular productivity study. This study shows that, despite the sensitivity of the calculations, the range of values for TFP which emerge are sufficiently reliable to provide a guide to overall productivity performance, it is just that they are not as precise as is often assumed.

ACKNOWLEDGMENTS

The authors acknowledge financial assistance from Transport Canada, Canadian National Railway, Canadian Pacific Railway, the Social Sciences and Humanities Research Council, and the University of British Columbia; also the helpful comments and discussions with personnel at the two railways and Transport Canada who were generous with advice and suggestions but gave complete freedom in analyzing and interpreting the data, and helpful discussions with D.A. Hensher and T.H. Oum.

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